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Fifty-Year Flood-Inundation Maps for La Ceiba, Honduras

U.S. Geological Survey Open-File Report 02-254

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By David L. Kresch, Mark C. Mastin, and Theresa D. Olsen

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

Multiply	By	To obtain
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

VERTICAL DATUM

Elevation: In this report "elevation" refers to the height, in meters, above the ellipsoid defined by the World Geodetic System of 1984 (WGS 84).

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ABSTRACT

After the devastating floods caused by Hurricane Mitch in 1998, maps of the areas and depths of the 50-year-flood inundation at 15 municipalities in Honduras were prepared as a tool for agencies involved in reconstruction and planning. This report, which is one in a series of 15, presents maps of areas in the municipality of La Ceiba that would be inundated by a 50-year-flood of Río Cangrejal. Geographic Information System (GIS) coverages of the flood inundation are available on a computer in the municipality of La Ceiba as part of the Municipal GIS project and on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html). These coverages allow users to view the flood inundation in much more detail than is possible using the maps in this report.

Water-surface elevations for a 50-year-flood discharge of 1,030 cubic meters per second on Río Cangrejal at La Ceiba were computed using HEC-RAS, a one-dimensional, steady-flow, step-backwater computer program. The channel and floodplain cross sections used in HEC-RAS were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of the area. There are no nearby long-term stream-gaging stations on Río Cangrejal; therefore, the 50-year-flood discharge for Río Cangrejal at La Ceiba was estimated using a regression equation that relates the 50-year-flood discharge to drainage area and mean annual precipitation. The drainage area and mean annual precipitation estimated for Río Cangrejal at La Ceiba are 498 square kilometers and 2,306 millimeters, respectively.

INTRODUCTION

In late October 1998, Hurricane Mitch struck the mainland of Honduras, triggering destructive landslides, flooding, and other associated disasters that overwhelmed the country's resources and ability to quickly rebuild itself. The hurricane produced more than 450 millimeters (mm) of rain in 24 hours in parts of Honduras and caused significant flooding along most rivers in the country. A hurricane of this intensity is a rare event, and Hurricane Mitch is listed as the most deadly hurricane in the Western Hemisphere since the "Great Hurricane" of 1780. However, other destructive hurricanes have hit Honduras in recent history. For example, Hurricane Fifi hit Honduras in September 1974, causing 8,000 deaths (Rappaport and Fernandez-Partagas, 1997).

As part of a relief effort in Central America, the U.S. Agency for International Development (USAID), with help from the U.S. Geological Survey (USGS), developed a program to aid Central America in rebuilding itself. A top priority identified by USAID was the need for reliable flood-hazard maps of Honduras to help plan the rebuilding of housing and infrastructure. The Water Resources Division of the USGS in Washington State, in coordination with the International Water Resources Branch of the USGS, was given the task to develop flood-hazard maps for 15 municipalities in Honduras: Catacamas, Choloma, Choluteca, Comayagua, El Progreso, Juticalpa, La Ceiba, La Lima, Nacaome, Olanchito, Santa Rosa de Aguán, Siguatepeque, Sonaguera, Tegucigalpa, and Tocoa. This report presents and describes the determination of the area and depth of inundation in the municipality of La Ceiba that would be caused by a 50-year flood of Río Cangrejal.

The 50-year flood was used as the target flood in this study because discussions with the USAID and the Honduran Public Works and Transportation Ministry indicated that it was the most common design flood used by planners and engineers working in Honduras. The 50-year flood is one that has a 2-percent chance of being equaled or exceeded in any one year and on average would be equaled or exceeded once every 50 years.

Purpose, Scope, and Methods

This report provides (1) results and summary of the hydrologic analysis to estimate the 50-year-flood discharge used as input to the hydraulic model, (2) results of the hydraulic analysis to estimate the water-surface elevations of the 50-year-flood discharge at cross sections along the stream profile, and (3) 50-year-flood inundation maps for Río Cangrejal at La Ceiba showing area and depth of inundation.

The analytical methods used to estimate the 50-year-flood discharge, to calculate the water-surface elevations, and to create the flood-inundation maps are described in a companion report by Mastin (2002). Water-surface elevations along Río Cangrejal were calculated using HEC-RAS, a one-dimensional, steady-flow, step-backwater computer model; and maps of the area and depths of inundation were generated from the water-surface elevations and topographic information.

The channel and floodplain cross sections used in HEC-RAS were developed from an airborne light-detection-and-ranging (LIDAR) topographic survey of La Ceiba and ground surveys at two bridges. Because of the high cost of obtaining the LIDAR elevation data, the extent of mapping was limited to areas of high population density where flooding is expected to cause the most damage. The findings in this report are based on the condition of the river channel and floodplains on March 9, 2000, when the LIDAR data were collected, and March 22, 2000 and January 14, 2001, when the bridges were surveyed.

Acknowledgments

We acknowledge USAID for funding this project; Jeff Phillips of the USGS for providing data and field support while we were in-country; and Roger Bendeck, a Honduran interpreter, for being an indispensable guide, translator, and instrument man during our field trips.

DESCRIPTION OF STUDY AREA

Río Cangrejal flows through the eastern section of La Ceiba. The study area includes the channel and floodplains of Río Cangrejal from approximately 2 kilometer (km) upstream from La Ceiba to its mouth at the Caribbean Sea (figure 1).

The headwaters of Río Cangrejal are in the Cordillera Nombre de Dios south of the study area. The streambed material consists primarily of sand and gravel with a few small to medium cobbles. The main channel banks and floodplains are generally covered with light to moderate vegetation.

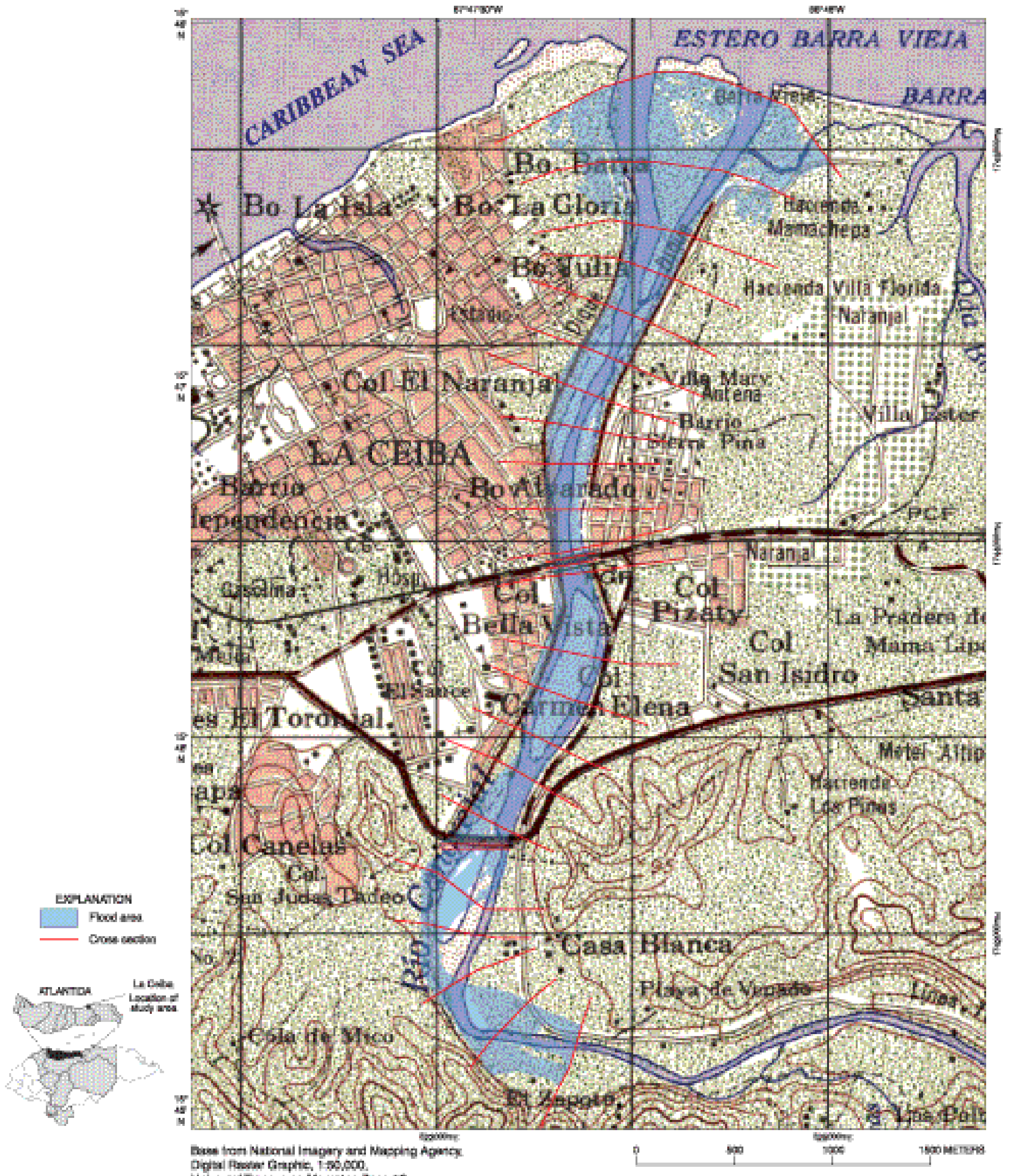

Figure 1. Location of study area and cross sections, and the area of inundation for the 50-year flood on Río Cangrejal at La Ceiba, Honduras.

FIFTY-YEAR FLOOD DISCHARGE

There are no long-term stream-gaging stations on Río Cangrejal; therefore, the 50-year-flood discharge was estimated using the following regression equation, which was developed using data from 34 streamflow stations throughout Honduras with more than 10 years of annual peak flow record, that relates the 50-year peak flow with drainage basin area and mean annual precipitation (Mastin, 2002).

$$Q_{50} = 0.0788(DA)^{0.5664}(P)^{0.7693}\ , \qquad (1)$$

where

Q_{50} is the 50-year-flood discharge, in cubic meters per second (m^3/s),

DA is drainage area, in square kilometers (km^2), and

P is mean annual precipitation over the basin, in mm.

The standard error of estimate of equation 1, which is a measure of the scatter of data about the regression equation, is 0.260 log unit, or 65.6 percent. The standard error of prediction, which is a measure of how well the regression equation predicts the 50-year-flood discharge and includes the scatter of the data about the equation plus the error in the regression equation, equals 0.278 log unit, or 71.3 percent

The drainage area of Río Cangrejal at La Ceiba was calculated to be 498 km^2 using a geographic information system (GIS) program to analyze a digital elevation model (DEM) with a 93-meter cell resolution from the U.S. National Imagery and Mapping Agency (David Stewart, USGS, written commun., 1999). The mean annual precipitation over the Río Cangrejal drainage basin was calculated to be 2,306 mm, using a GIS program to analyze a digitized map of mean annual precipitation at a scale of 1:2,500,000 (Morales-Canales, 1997–1998, p. 15).

The 50-year-flood discharge estimated from regression equation 1 for Río Cangrejal at La Ceiba is 1,030 m^3/s.

WATER-SURFACE PROFILE OF THE 50-YEAR FLOOD

Once a 50-year flood discharge has been estimated, a profile of water-surface elevations along the course of the river can be estimated for the 50-year flood with a step-backwater model, and later used to generate the flood-inundation maps. The U.S. Army Corps of Engineers HEC-RAS modeling system was used for step-backwater modeling. HEC-RAS is a one-dimensional, steady-flow model for computing water-surface profiles in open channels, through bridge openings, and over roads. The basic required inputs to the model are stream discharge, cross sections (geometry) of the river channels and floodplains perpendicular to the direction of flow, bridge geometry, Manning's roughness coefficients (*n* values) for each cross section, and boundary conditions (U.S. Army Corps of Engineers, 1998).

Cross-section geometry was obtained from a high-resolution DEM created from an airborne LIDAR survey. The LIDAR survey was conducted by personnel from the University of Texas. A fixed-wing aircraft with the LIDAR instrumentation and a precise global positioning system (GPS) flew over the study area on March 9, 2000. The relative accuracy of the LIDAR data was determined by comparing LIDAR elevations with GPS ground-surveyed elevations at 245 points in the La Ceiba study area. The mean difference between the two sets of elevations is -0.302 meter, and the standard deviation of the differences is 0.077 meter. The LIDAR data were filtered to remove vegetation while retaining the buildings to create a "bare earth" elevation representation of the floodplain. The LIDAR data were processed into a GIS (Arc/Info™) GRID raster coverage of elevations at a 1.5-meter cell resolution.

The coverage was then processed into a triangular irregular network (TIN) GIS coverage. Cross sections of elevation data oriented across the floodplain perpendicular to the expected flow direction of the 50-year-flood discharge (figure 1) were obtained from the TIN using HEC-GeoRAS, a pre- and post-processing GIS program designed for HEC-RAS (U.S. Army Corps of Engineers, 2000). The underwater portions of the cross sections cannot be seen by the LIDAR system. However, because the LIDAR surveys were conducted during a period of extremely low flows, the underwater portions were assumed to be insignificant in comparison with the cross-sectional areas of flow during a 50-year flood; therefore, they were not included in the model.

Two bridges cross Rio Cangrejal in La Ceiba. The geometry of the upstream bridge, located at station 4.580, was surveyed during a field visit on March 22, 2000. At the time of that survey construction work was underway to replace a bridge pier that had been undermined by Hurricane Mitch flood flows. The bridge survey indicated that the elevation of the part of the bridge deck supported by that pier had decreased by about 0.9 meter. The remains of the downstream bridge, which was significantly damaged during Hurricane Mitch, had been removed and construction of a new bridge had already begun at the time of the March 22 field visit. The geometry of the completed new bridge, located at station 2.987, was surveyed during a field visit on January 14, 2001.

Most hydraulic calculations of flow in channels and overbank areas require an estimate of flow resistance, which is generally expressed as Manning's roughness coefficient, *n*. The effect that roughness coefficients have on water-surface profiles is that as the *n* value is increased, the resistance to flow increases also, which results in higher water-surface elevations. Roughness coefficients (Manning's *n*) for Rio Cangrejal were estimated from digital photographs taken during field visits of the study area on March 22, 2000, and January 14, 2001, and from computer displays of shaded-relief images of the LIDAR-derived DEM before any vegetation removal filter was applied. The *n* values estimated for the main channel range from 0.032 at the upstream end to 0.028 at the mouth and the *n* values estimated for the floodplain areas range from 0.040 to 0.065.

Step-backwater computations require a water-surface elevation as a boundary condition at either the downstream end of the stream reach for flows in the subcritical flow regime or at the upstream end of the reach for flows in the supercritical flow regime. Initial HEC-RAS simulations indicated that the flow in Río Cangrejal would be in the subcritical flow regime. Therefore, the boundary condition used was a water-surface elevation at cross-section 0.370, the farthest downstream cross section in the Río Cangrejal step-backwater model. This elevation, 1.42 meters, was estimated by a slope-conveyance computation assuming an energy gradient of 0.001, which was estimated to be equal to the slope of the main channel bed. The computed water-surface elevations at the first few cross sections upstream may differ from the true elevations if the estimated boundary condition elevation is incorrect. However, if the error in the estimated boundary condition is not large, the computed profile asymptotically approaches the true profile within a few cross sections.

A model run was also made to determine the approximate effects on Río Cangrejal water-surface elevations of the simultaneous occurrence of a storm tide in the Caribbean Sea and a 50-year flood of Río Cangrejal. The downstream boundary condition used for this run, 2.4 meters at cross-section 0.370, was based on an estimate that a typical Caribbean Sea storm tide in the vicinity of La Ceiba would be approximately a few meters above the astronomical high tide. The effects on Río Cangrejal water-surface elevations were minimal. The water-surface elevation at cross-section 0.808, the next section upstream, increased by only 0.5 meter, and the elevation at cross-section 1.169, the next section upstream, increased by only 0.04 meter.

The step-backwater model provided estimates of water-surface elevations at all cross sections for the 50-year-flood discharge (table 1 and figure 2).

Table 1. Estimated water-surface elevations for the 50-year-flood on Río Cangrejal at La Ceiba, Honduras

[Peak flow for hte 50-year flood is 1,030 cubic meters per second. **Cross-section stationing**: distance upstream from an arbitrary point near the model boundary; **Minimum channel elevation**, **Water-surface elevation**: elevations are referenced to the World Geodetic System Datum of 1984; **Abbreviations**: km, kilometers; m, meters; m/s, meters per second]

Cross-section stationing (km)	Minimum channel elevation (m)	Average velocity of flow (m/s)	Water-surface elevation (m)
6.161	13.33	2.31	16.74
5.743	11.13	1.92	14.65
5.395	10.49	2.43	13.90
5.063	9.90	3.90	12.49
4.839	8.50	2.86	11.32
4.583	7.05	2.30	10.45
4.580 (bridge)			
4.568	7.05	2.38	10.37
4.439	7.30	2.21	10.13
4.132	6.43	2.85	9.22
3.931	6.02	3.18	8.44
3.685	4.65	2.87	7.38
3.462	3.56	1.85	6.83
3.050	3.00	2.29	6.14
2.990	2.64	2.55	5.92
2.987 (bridge)			
2.974	2.64	2.69	5.80
2.926	2.60	2.48	5.78
2.708	2.60	2.43	5.45
2.475	2.44	2.71	4.88
2.279	2.16	2.31	4.49
2.090	1.94	2.13	4.22
1.881	1.62	1.98	3.96
1.637	1.23	2.16	3.60
1.390	0.96	2.38	3.08
1.169	0.66	2.15	2.64
0.808	0.25	1.65	1.97
0.370	0.05	1.04	1.42

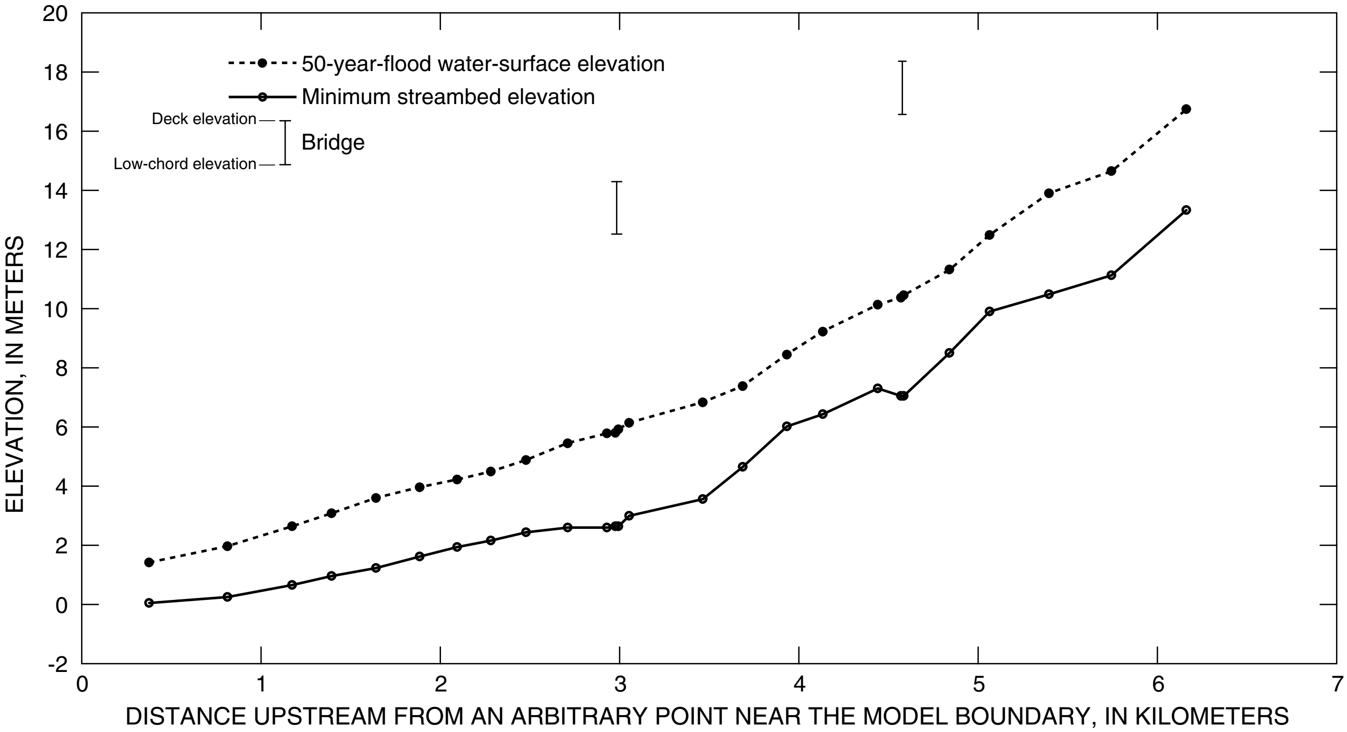

Figure 2. Water-surface profile, estimated using the step-backwater model HEC-RAS, for the 50-year flood on Río Cangrejal at La Ceiba, Honduras.

FIFTY-YEAR FLOOD-INUNDATION MAPS

The results from the step-backwater hydraulic model were processed by the computer program HEC-GeoRAS to create GIS coverages of the area and depth of inundation for the study area. The GIS coverage of area of inundation was created by intersecting the computed water-surface elevations with the topographic TIN that was produced from the LIDAR data. This coverage was then overlain on an existing 1:50,000 topographic digital raster graphics map (figure 1) produced by the U.S. National Imagery and Mapping Agency (Gary Fairgrieve, USGS, written commun., 1999). The area of inundation is confined to the main channel by a combination of levees and high banks from about 1 km upstream from the mouth of Río Cangrejal to the bridge at cross-section 4.580. Upstream of the bridge the area of inundation is confined by high banks to the main channel and a well-defined floodplain. The undeveloped area of La Ceiba near the mouth of Río Cangrejal is susceptible to shallow flooding because the west-bank levee does not extend all the way to the mouth and because there are some small openings in the east-bank levee that would allow floodwaters to flow through. Depth of inundation at La Ceiba for a 50-year-flood on Río Cangrejal (figure 3) was computed by subtracting the topographic TIN from a computed water-surface elevation TIN to produce a grid with a cell size of 2 meters.

The flood-hazard maps are intended to provide a basic tool for planning or for engineering projects in or near the Río Cangrejal floodplain. This tool can reasonably separate high-hazard areas from low-hazard areas in the floodplain to minimize future flooding losses. However, significant introduced or natural changes in main-channel or floodplain geometry or location can affect the area and depth of inundation. Also, encroachment into the floodplain with structures or fill will reduce flood-carrying capacity and thereby increase the potential height of floodwaters, and may also increase the area of inundation.

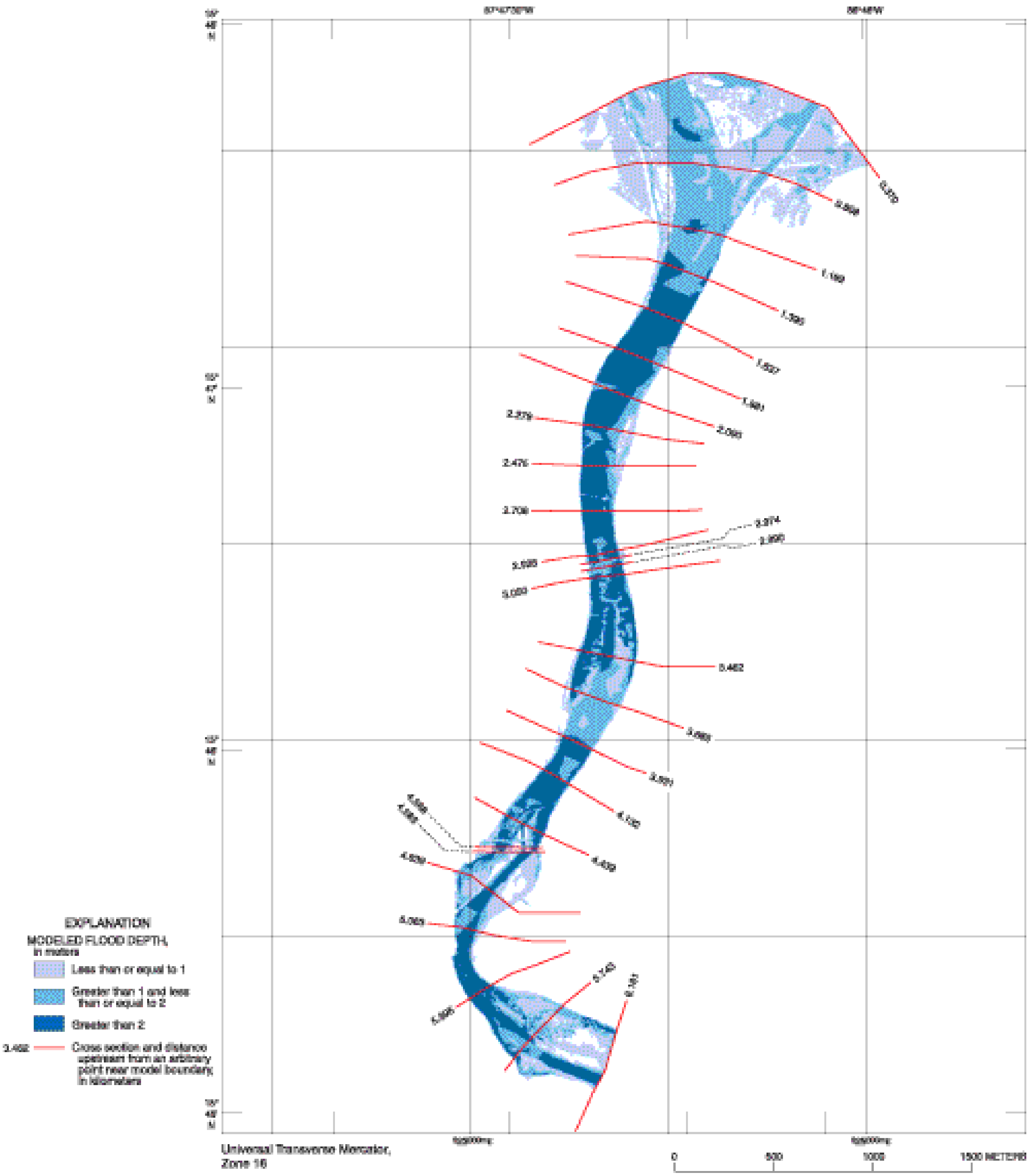

Figure 3. Depth of inundation of the 50-year flood and location of cross sections on Río Cangrejal at La Ceiba, Honduras.

DATA AVAILABILITY

GIS coverages of flood inundation and flood depths shown on the maps in figures 1 and 3 are available in the Municipal GIS project, a concurrent USAID-sponsored USGS project that will integrate maps, orthorectified aerial photography, and other available natural resource data for a particular municipality into a common geographic database. The GIS project, which is located on a computer in the La Ceiba municipality office, allows users to view the GIS coverages in much more detail than shown on figures 1 and 3. The GIS project will also allow users to overlay other GIS coverages over the inundation and flood-depth boundaries to further facilitate planning and engineering. Additional information about the Municipal GIS project is available on the Internet at the GIS Products Web page (http://mitchnts1.cr.usgs.gov/projects/gis.html), a part of the USGS Hurricane Mitch Program Web site.

The GIS coverages and the HEC-RAS model files for this study are available on the Internet at the Flood Hazard Mapping Web page (http://mitchnts1.cr.usgs.gov/projects/floodhazard.html), which is also a part of the USGS Hurricane Mitch Program Web site.

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